7. Financial parameters

This section presents all the major financial parameters of WinDS. It begins with general economic parameters that are used in the WinDS economic calculations.

General Economic Parameters

d is a discount rate—as used in WinDS, it represents the annual investor return
d_r is a real discount rate, i.e. the rate of return above inflation
d_n is a nominal discount rate, i.e. the rate of return including inflation
E is the evaluation period or investment lifetime (years)
$PVA_{d,E}$ is the present value of annual \$1 payments for E years

$$PVA_{d,E} = \sum_{t=1}^{E} (1+d)^{-t} = (1 - 1/(1+d)^{L})/d$$

$PVA_{name,d,E,n}$ is the present value of annual fuel costs for technology q in PCA n escalating annually for E years.

$$PVA(q,n)_{d,E,e} = Fprice_{q,n} \sum_{t=1}^{E} (1+e)^{t} / (1+d)^{t}$$

$CRF_{d,E}$ is the capital recovery factor computed at discount rate d for E years, i.e. the fraction of the capital cost (CC) of an investment that must be returned each year to earn a rate of return equal to d if income taxes and financing are ignored.

$$CC = \sum_{t=1}^{E} CC * CRF_{d,E} / (1+d)^{t}$$

$$CRF_{d,E} = 1 / \sum_{t=1}^{E} (1+d)^{-t} = d / (1 - 1/(1+d)^{E})$$

Or

$$CRF_{d,E} = 1/PVA_{d,E}$$

Financial Parameters Specific to Wind

This subsection includes many of the cost parameters that are calculated for wind.

CW_c is the present value of the revenue required to pay for the capital cost of one MW of wind capacity (\$/MW) including interest during construction, finance, and taxes

$$CW_c = WCC_c * IDC / (1-TR) * \begin{bmatrix} (1-FF) + FF * PVDebt \\ -TR * (1 - ITCW/2) * PVDep - ITCW \end{bmatrix}$$

Where:

$\mathbf{WCC_c}$ is the overnight capital cost ($/MW) of the wind plant. WCC_c can be either a direct input (IWLC=0) or calculated based on a production learning curve. (IWLC = 1).

If learning-based improvements are allowed (ILC=1), then

$\mathbf{WCC_c}$ =WCC_o*[(1-costinstfrac)
*(1-$learnpar_{wind}$)^(log(WROW+$WindCap_{T\_delay}$/W_o)/log(2))
+ **constinstfrac*(1-**$learnpar_{wind}$**)^(log(**$WindCap_{T\_delay}$/W_UScapyr2000)/log(2))]

Where:

$\mathbf{WCC_o}$ is the overnight capital cost ($/MW) of wind without learning as input for the time period (i.e., includes any R&D driven changes over time, but not learning)

costinstfrac is the fraction of the capital cost associated with installation

$\mathbf{learnpar_{wind}}$ is the learning parameter for wind, or the % reduction in the capital cost of wind for each doubling of the installed capacity

WROW is the wind capacity installed in the rest of the world T_delay periods ago

T_delay is the time required for learning to impact the market, i.e. the learning delay in periods between installations and cost reductions

$\mathbf{WindCap_{T\_delay}}$ is the total national installed wind capacity T_delay periods ago

W_UScapyr2000 is the total national capacity in the year 2000

$\mathbf{W_o}$ is the total world wind capacity in the year 2000

IDC = multiplier to capture after-tax value of interest during construction

$$IDC = \sum_{t=1}^{CP} CONSF_t * [1 + (1 - TR) * \{(1 + i_c)^{CP-t} - 1\}]]$$

Where:

$\mathbf{CONSF_t}$ is the fraction of the capital cost incurred in year t of construction

$\mathbf{i_c}$ is the construction loan nominal interest rate

CP is the construction period

TR = combined federal and state marginal income tax rate

FF = fraction of the plant capital cost financed. It can be input or calculated as shown below (see DSCR discussion) to ensure that the required debt service coverage ratio (DSCR) is met.

PVDebt is the after-tax present value of debt payments.[8]

[8] Closed-form expression for the after-tax present value of the loan payments
Define Pt as the principal payment in year t, and i as the nominal interest rate, then the cost of the loan payments over the life L of the loan is:

$$PVDebt = \sum_{t=1}^{L} (P_t + (1-TR)I_t)/(1+d_n)^t$$
$$= CRF_{i,L} * (1-TR) * PVA_{d_n,L} + TR * (CRF_{i,L} - i)/(1+i) * PVA_{d_n^{'},L}$$

Where:

P_t is the principal portion of the finance payment made after the loan has been in place t years

I_t is the interest portion of the finance payment made after the loan has been in place t years

i = nominal interest rate for debt

L = financing period

d_n' = $(1+d_n)/(1+i) - 1$

ITCW = investment tax credit for wind

PVDep is the present value of depreciation

$$PVDep = \sum_{t=1}^{DP} Depf_t /(1+d_n)^t$$

Where:

$Depf_t$ = depreciation fraction in year t

DP = depreciation period

CWOMc is the present value of E years of operating costs including property taxes, insurance, and production tax credit ($/MW)

$$CWOM_c = WOMF_c * PVA_{d_r,E} + 8760 * CF_c * (WOMV_c * PVA_{d_r,E} - WPTC/(1-TR) * PVA_{d_r,PTCP})$$

$$\sum_{t=1}^{L} (P_t + (1-TR)I_t)/(1+d_n)^t = \sum_{t=1}^{L} (P_t + (1-TR) * (CRF_{i,L} - P_t))/(1+d_n)^t$$
$$= \sum_{t=1}^{L} CRF_{i,L} * (1-TR)/(1+d_n)^t + \sum_{t=1}^{L} P_t * TR/(1+d_n)^t$$
$$= \sum_{t=1}^{L} CRF_{i,L} * (1-TR)/(1+d_n)^t + TR\sum_{t=1}^{L} P_1 * (1+i)^{t-1}/(1+d_n)^t$$
$$= CRF_{i,L} * (1-TR) * \sum_{t=1}^{L} 1/(1+d_n)^t + TR * P_1/(1+i) * \sum_{t=1}^{L} (1+i)^t/(1+d_n)^t$$
$$= CRF_{i,L} * (1-TR) * PVA_{d_n,L} + TR * (CRF_{i,L} - i)/(1+i) * PVA_{d_n^{'},L}$$

where: d_n' = $(1+d_n)/(1+i) - 1$

Where:[9]

$WOMF_c$ is the fixed annual O&M cost of class c wind ($/MW-yr)
$WOMV_c$ is the variable O&M cost of class c wind ($/MWh)
WPTC is the production tax credit ($/MWh)
d_r is the real discount rate (assumes WOMF, WOMC, and WPTC do not change in real terms, i.e. they increase at the same rate as inflation)
PTCP is the period over which the production tax credit is received (years)
E is the evaluation period

CG_g is the increase in turbine price over cost due to rapid growth in wind deployment

$CG_1 = 0.01$
$CG_2 = (1\text{-Cost\_Inst\_Frac})*CW_6*GP*(BP_2-BP_1)/2$
$CG_3 = (1\text{-Cost\_Inst\_Frac})*CW_6*GP*(BP_2-BP_1+(BP_3-BP_2)/2)$
$CG_4 = (1\text{-Cost\_Inst\_Frac})*CW_6*GP*(BP_3-BP_1+(BP_4-BP_3)/2)$
$CG_5 = (1\text{-Cost\_Inst\_Frac})*CW_6*GP*(BP_4-BP_1+(BP_5-BP_4)/2)$
$CG_6 = (1\text{-Cost\_Inst\_Frac})*CW_6*GP*(BP_5-BP_1)$

Where:

CW_6 is the cost of a class 6 wind machine
GP is the growth penalty for each percent growth above the breakpoint
BP_k are breakpoints that discretize the growth price penalty
$(1<BP_1<BP_2<BP_3<BP_4<BP_5<BP_6)$

$CGinst_{ginst}$ is the increase in wind installation price over cost in growth bin ginst, due to rapid growth in wind deployment ($/MW)

$CGinst_1 = 0.01$
$CGinst_2 = \text{Cost\_Inst\_Frac}*CW_6*GPinst*(BP_2-BP_1)/2$
$CGinst_3 = \text{Cost\_Inst\_Frac}*CW_6*GPinst*(BP_2-BP_1+(BP_3-BP_2)/2)$
$CGinst_4 = \text{Cost\_Inst\_Frac}*CW_6*GPinst*(BP_3-BP_1+(BP_4-BP_3)/2)$
$CGinst_5 = \text{Cost\_Inst\_Frac}*CW_6*GPinst*(BP_4-BP_1+(BP_5-BP_4)/2)$
$CGinst_6 = \text{Cost\_Inst\_Frac}*CW_6*GPinst*(BP_5-BP_1)$

Where:

GPinst is the growth penalty for each percent growth above the breakpoint

[9] The use of a real discount rate in all the O&M calculations presumes that the O&M costs increase with inflation, i.e. that the real O&M cost is unchanging.

Setting the Finance Fraction in WinDS

The fraction of the capital cost of a wind farm that is financed can be input or endogenously estimated based on debt-service requirements. If calculated endogenously, the maximum fraction that can be financed is used. The fraction that can be financed is restricted by the Debt Service Coverage Ratio (DSCR). DSCR is the ratio of net pre-tax revenue to the debt payment (Debtpayment). WinDS assumes the net pre-tax revenue is equal to the revenue required to recover capital cost plus profit and tax benefits (e.g., production tax credit).

$$DSCR = \mathrm{CRF}_{\mathrm{d_n,E}} * (\mathrm{CW_c} + \mathrm{WPTC} * 8760 * \mathrm{CF_c}/(1 - \mathrm{TR}) * \mathrm{PVA}_{\mathrm{d_r,PTCP}})/\ \mathrm{Debtpayment}$$

Where:

$$Debtpayment = FF * WCC * IDC * CRF_{i,L}$$

Solving the DSCR equation for the finance fraction (which is embedded in CW_c as well) yields

$$\begin{aligned} FF = {} & CRF_{d,E} * (\mathrm{WPTC} * 8760 * \mathrm{CF_c}/(1 - \mathrm{TR}) * \mathrm{PVA}_{\mathrm{d_r,PTCP}} \\ & + WCC * IDC/(1 - TR) * (1 - TR * (1 - ITCW/2) * PVDep - ITCW))/ \\ & (WCC * IDC * [DSCR * CRF_{i,L} + (1 - PVDebt) * CRF_{d,E}/(1 - TR)]) \end{aligned}$$

Financial Parameters Specific to Conventional Technologies

This section includes many of the cost parameters that are calculated in WinDS for conventional technologies. Inasmuch as some of these are substantively the same as those calculated for wind, the reader will be referred to the above wind parameter subsection.

CCONVq is the present value of the revenue required to pay for the capital cost of one MW of capacity of generating technology q ($/MW) including interest during construction, finance, and taxes. It is calculated in a manner analogous to that for wind.

$$CCONV_q = CCC_q * \left(CRF_{d_r,E} / CRF_{d_r,L_q}\right) * IDC/(1 - TR) * \begin{bmatrix} (1 - FF) + FF * PVDebt \\ - TR * (1 - ITC_q/2) * PVDep - ITC_q \end{bmatrix}$$

Where:

CCC_q is the overnight capital cost ($/MW) of the generation plant. **CCC_q** can be either a direct input (ILC=0) or calculated based on a production learning curve. (ILC = 1).

If learning-based improvements are allowed (ILC=1), then

CCC_q =CCC_o*(1-learnpar$_q$)^(log(CONVOLDdelay$_q$/USCapyr2000$_q$)/log(2))

Where:

CCC_o is the overnight capital cost of generating technology q without learning as input for the time period (i.e., includes any R&D driven changes over time, but not learning)
$CONVOLDdelay_q$ is the total national installed wind capacity learndelay periods ago
learndelay is the learning delay between installations and cost reductions
$USCapyr2000_q$ is the total national capacity of generation technology q in the year 2000
$learnpar_q$ is the learning parameter for generation technology q or the % reduction in the capital cost for each doubling of the installed capacity
L_q is the economic lifetime of technology q (years)
FF is the finance fraction which must be input for conventional technologies (unlike the endogenous calculation option for wind described above)
See the calculation of CW_c for the definition of the other inputs for CCC_q

$CCONVV_{n,q}$ is the present value of the variable cost of operating technology q in PCA n for E years

$$CCONVV_{n,q} = CVarOM_q * PVA_{d_r,E} + Fprice_{q,n} * cheatrate_q * PVA(n,q)_{d_r,E,e}$$

Where:

$CvarOM_q$ is the variable O&M cost for technology q ($/MWh)
$Fprice_{q,n}$ is the cost of the input fuel ($/MMBtu)
$cheatrate_q$ is the heat rate for technology q

$CCONVF_q$ is the present value of the fixed costs of operating technology q for E years ($/MW)

$$CCONVF_q = COMF_q*PVA_{dr,E}$$

Where:

$COMF_q$ is the annual fixed O&M cost for plant type q ($/MW-yr)

$CSRV_{n,q}$ is the present value of the variable cost of spinning reserve provided for E years in PCA n ($/MWh). The cost represents the cost of operating the plant at part-load. A linear program cannot ordinarily capture part-load efficiency, because it is highly nonlinear with the level of operation. WinDS assumes that if spinning reserve is provided, the maximum amount is provided in the time slice, the plant is operating at MinSRq*CONVCAPq,n. Thus, the cost of spinning reserve can be estimated by solving the following for CSRVn,q:

$$CCONVV_{q,n} * (MinSR_q * CONV_{q,n}) / PLEffFactor_q$$
$$= CCONVV_{q,n} * (MinSR_q * CONV_{q,n}) + (1 - MinSR_q) * CONV_{q,n} * CSRV_{n,q}$$

or

$$CSRV_{n,q} = MinSR_q / (1 - MinSR_q) * CCONVV_{q,n} * (1 / PLEffFactor_q - 1)$$

Transmission Cost Parameters

$CCT_{n,p}$ is the present value of transmitting 1 MWh of power for each of E years between PCAs n and p ($/MWh)

$$CCT_{n,p} = (Dis_{n,p}*TOCOST + POSTSTWCOST*PostStamp_{n,p}))*PVA_{dn,E}$$

Where:

$Dis_{n,p}$ is the distance in miles between the center of PCAs n and p
TOCost is the cost per mile for using existing transmission lines ($/MWh-mile).
POSTSTWCOST is the cost of using transmission that crosses a PCA ($/MWh)
$PostStamp_{n,p}$ is the number of PCAs that must be crossed to move from PCA n to PCA p. If p is not the same as n, PCA p is counted as one PCA to be crossed.

$TPCA\_CG_{tpca\_g}$ is the difference between the price and cost of transmission in transmission growth bin tpca_g ($/MW-mile).

$TPCA\_CG_1 = 0.01$

$TPCA\_CG_2 = TNCost * TPCAGP * (TPCACC(TPCABP_2) – TPCACC(TPCABP_1))/2$

$TPCA\_CG_3 = TNCost * TPCAGP * [(TPCACC(TPCABP_2) – TPCACC(TPCABP_1))+(TPCACC(TPCABP_3) – TPCACC(TPCABP_2))/2]$

$TPCA\_CG_4 = TNCost * TPCAGP * [(TPCACC(TPCABP_3) – TPCACC(TPCABP_1))+(TPCACC(\_TPCABP_4) – TPCACC(TPCABP_3))/2]$

$TPCA\_CG_5 = TNCost * TPCAGP * [(TPCACC(TPCABP_4) – TPCACC(TPCABP_1))+(TPCACC(TPCABP_5) – TPCACC(TPCABP_4))/2]$

$TPCA\_CG_6 = TNCost * TPCAGP * [TPCACC(TPCABP_5) – TPCACC(TPCABP_1)]$

Where:

TPCA_GP is the percent increase in the cost of transmission for each percent growth over the base amount

$TPCACC(TPCABP_k)$ is the fractional breakpoint associated with step k of the growth curve

$TPCACC(TPCABP_5) > TPCACC(TPCABP_4) > TPCACC(TPCABP_3) > TPCACC(TPCABP_2) > TPCACC(TPCABP_1 > 1)$

CILA is the present value of the cost to a utility for 1 MW of interruptible load over the evaluation period of E years ($/MW)

$$CILA = CIL * PVA_{dr,E}$$

Where CIL is the annual cost of one MW of interruptible service

CIL_{ilg} is the present value over the evaluation period of the cost of higher levels of interruptible load than the base level ($/MWh). A supply curve is used for each PCA to capture the cost of larger amounts of interruptible load supply. The subscript ilg denotes the discrete step of the supply curve. For the ilg step of the supply curve, CIL_{ilg} provides the additional cost of interruptible load over the base amount.

$CIL_1 = 0.01$

$CIL_2 = CILA * ILGP * (CIL\_SC(ILBP_2) – CIL\_SC(ILBP_1))/2$

$CIL_3 = CILA * ILGP * [(CIL\_SC(ILBP_2) – CIL\_SC(ILBP_1))+(CIL\_SC(ILBP_3) – CIL\_SC(ILBP_2))/2]$

$CIL_4 = CILA * ILGP * [(CIL\_SC(ILBP_3) – CIL\_SC(ILBP_1))+(CIL\_SC(ILBP_4) – CIL\_SC(ILBP_3))/2]$

$CIL_5 = CILA * ILGP * [(CIL\_SC(ILBP_4) – CIL\_SC(ILBP_1))+(CIL\_SC(ILBP_5) – CIL\_SC(ILBP_4))/2]$

$CIL_6 = CILA * ILGP * [CIL\_SC(ILBP_5) – CIL\_SC(ILBP_1)]$

Where:

ILGP is the fractional increase in the cost of interruptible load for each percent increase over the base amount

$CIL\_SC(ILBP_k)$ is the fractional breakpoint associated with step k of the supply curve ($CIL\_SC(ILBP_5 > CIL\_SC(ILBP_4 > CIL\_SC(ILBP_3 > CIL\_SC(ILBP_2 > CIL\_SC(ILBP_1 > 1$)

Hydrogen Cost Parameters

$CGelectrolyzer_{hebp}$ is the increase in growth step hebp in electrolyzer price over cost due to rapid growth in electrolyzer deployment ($/kg-year)

$CGelectrolyzer_1$ = 0.01

$CGelectrolyzer_2$ = $CCH2electrolyzer * GPElec*(EGR(HEBP_2)-EGR(HEBP_1))/2$

$CGelectrolyzer_3$ = $CCH2electrolyzer * GPElec*(EGR(HEBP_2)-EGR(HEBP_1)+(EGR(HEBP_3)-EGR(HEBP_2))/2)$

$CGelectrolyzer_4$ = $CCH2electrolyzer * GPElec*(EGR(HEBP_3)-EGR(HEBP_1)+(EGR(HEBP_4)-EGR(HEBP_3))/2)$

$CGelectrolyzer_5$ = $CCH2electrolyzer * GPElec*(EGR(HEBP_4)-EGR(HEBP_1)+(EGR(HEBP_5)-EGR(HEBP_4))/2)$

$CGelectrolyzer_6$ = $CCH2electrolyzer * GPElec*(EGR(HEBP_5)-EGR(HEBP_1))$

Where:

CCH2electrolyzer is the cost of an electrolyzer ($/kg-yr)

GPElec is the growth penalty for each percent growth above the breakpoint

$EGR(HEBP_k)$ are breakpoints that discretize the growth price penalty

$1<EGR(HEBP_1)<EGR(HEBP_2)<EGR(HEBP_3)<EGR(HEBP_4)<EGR(HEBP_5))$

$CGSMR_{hsmrbp}$ is the increase in growth step hsmrbp in the price of a steam methane reformer over cost due to rapid growth in steam methane reformer deployment ($/kg-year)

CGSMR$_1$ = 0.01

CGSMR$_2$ = CCH2ng_reformer * GPSMR*(SMRGR(HSMRBP$_2$)-SMRGR(HSMRBP$_1$))/2

CGSMR$_3$ = CCH2 ng_reformer * GPSMR*(SMRGR(HSMRBP$_2$)-SMRGR(HSMRBP$_1$)+(SMRGR(HSMRBP$_3$)-SMRGR(HSMRBP$_2$))/2)

CGSMR$_4$ = CCH2 ng_reformer * GPSMR*(SMRGR(HSMRBP$_3$)-SMRGR(HSMRBP$_1$)+(SMRGR(HSMRBP$_4$)-SMRGR(HSMRBP$_3$))/2)

CGSMR$_5$ = CCH2 ng_reformer * GPSMR*(SMRGR(HSMRBP$_4$)-SMRGR(HSMRBP$_1$)+(SMRGR(HSMRBP$_5$)-SMRGR(HSMRBP$_4$))/2)

CGSMR$_6$ = CCH2 ng_reformer * GPSMR*(SMRGR(HSMRBP$_5$)-SMRGR(HSMRBP$_1$))

Where:

CCH2$_{\mathbf{ng\_reformer}}$ is the cost of a steam methane reformer ($/kg-yr)

GPSMR is the growth penalty for each percent growth above the breakpoint

SMRGR(HSMRBP$_{\mathbf{k}}$**)** are breakpoints that discretize the SMR growth price penalty

1<SMRGR(HSMRBP$_1$)<SMRGR(HSMRBP$_2$)<SMRGR(HSMRBP$_3$)<SMRGR(HSMRBP$_4$)<SMRGR(HSMRBP$_5$))

CGFC$_{\mathbf{hfcbp}}$ is the increase in growth step hfcbp in the price of a steam methane reformer over cost due to rapid growth in steam methane reformer deployment ($/kg-year)

CGFC$_1$ = 0.01

CGFC$_2$ = CCH2fuelcell * GPFC*(FCGR(HFCBP$_2$)-FCGR(HFCBP$_1$))/2

CGFC$_3$ = CCH2 fuelcell * GPFC*(FCGR(HFCBP$_2$)-FCGR(HFCBP$_1$)+(FCGR(HFCBP$_3$)-FCGR(HFCBP$_2$))/2)

CGFC$_4$ = CCH2 fuelcell * GPFC*(FCGR(HFCBP$_3$)-FCGR(HFCBP$_1$)+(FCGR(HFCBP$_4$)-FCGR(HFCBP$_3$))/2)

CGFC$_5$ = CCH2 fuelcell * GPFC*(FCGR(HFCBP$_4$)-FCGR(HFCBP$_1$)+(FCGR(HFCBP$_5$)-FCGR(HFCBP$_4$))/2)

CGFC$_6$ = CCH2 fuelcell * GPFC*(FCGR(HFCBP$_5$)-FCGR(HFCBP$_1$))

Where:

CCH2$_{\mathbf{fuelcell}}$ is the cost of a steam methane reformer ($/kg-yr)

GPFC is the growth penalty for each percent growth above the breakpoint

FCGR(HFCBP$_{\mathbf{k}}$**)** are breakpoints that discretize the FC growth price penalty

1<FCGR(HFCBP$_1$)<FCGR(HFCBP$_2$)<FCGR(HFCBP$_3$)<FCGR(HFCBP$_4$)<FCGR(HFCBP$_5$))